TITLE: Raman Study of Phonon-Plasmon Coupling Modes in Tunnelling GaAs/AlAs SLs, Grown on [311] and [001] Surfaces

9th Int. Symp. "Nanostructures: Physics and Technology"
St Petersburg, Russia, June 18–22, 2001



# Raman study of phonon–plasmon coupling modes in tunnelling GaAs/AlAs SLs, grown on (311) and (001) surfaces

*V. A. Volodin*†, M. D. Efremov†, V. A. Sachcov‡, V. V. Preobrazhenski†, B. R. Semyagin†, E. A. Galaktionov§ and D. A. Orehov§

† Institute of Semiconductor Physics SB RAS, pr. Lavrentjeva 13, Novosibirsk 630090, Russia

‡ Institute of Sensor Microelectronics SB RAS, pr. Mira 55a, Omsk 644077, Russia

§ Novosibirsk State University, 630090, Pirogova 2, Novosibirsk, Russia

The undoped and doped GaAs/AlAs superlattices (SLs) grown by MBE on (100), (311)B surfaces and facet (311)A surface were studied using Raman spectroscopy. Thickness of GaAs layers of the studied SLs was varied from 1 to 10 monolayers (mls), thickness of AlAs barriers was 8 mls, the concentration of impurity (Si) in doped SLs was $2 \times 10^{18}$ cm$^{-3}$. Parameters of the SLs are shown in Table 1. The Raman spectra were registered at room

**Table 1.** Specifications of the studied superlattices $GaAs_nAlAs_m$.

| No | Substrate (311)A | Substrate (311)B | Substrate (001) | GaAs thikness, mls | AlAs thikness, mls | Periods |
|---|---|---|---|---|---|---|
| 1 | 1A | 1B | 1 | 10 | 8 | 100 |
| 2 | 2A | 2B | 2 | 6 | 8 | 100 |
| 3 | 3A | 3B | 3 | 4 | 8 | 200 |
| 4 | 4A | 4B | 4 | 2 | 8 | 300 |
| 5 | 5A | 5B | 5 | 1 | 8 | 400 |

temperature in quasibackscattering geometry in various polarization geometries. The line 514.5 nm of Ar laser was used. As one can see in Fig. 1, when the width of GaAs quantum wells decrease, the interaction of plasmons with the GaAs-like LO-phonons also decrease, but the interaction of plasmons with the AlAs-like LO phonons increase, and the intermixed mode AlAs-like LO-phonons with plasmons was observed. For relatively thick SLs (10 mls GaAs), the width of peaks for doped and undoped SL is nearly equal. In the case of doped sample the peak position shifted to higher energy region. The shift may be caused by intersubband optical plasmons interaction with optical phonons; meanwhile intrasubband contribution is negligible due to localization of electrons.

Some changes in spectra of doped and undoped SL 2 take place, but in the case of SLs 3–5, these changes are dramatic. The coupled modes (for doped SLs — marked as LP2) are shifted and broadened. Peaks resulting of scattering on TO modes in these samples are also a little broadened. The coupling modes in the case of very thin SLs are similar to coupling modes in 3D-case of doped $Ga_xAl_{(1-x)}As$ solid solutions [1]. According to simple appraising using the Kronig–Penny model in the case of SL 4 and 5 the electrons are practically delocalizated, what in good agreement in experimental data. As one can see, the coupled modes of plasmons with optical phonons of GaAs type (marked as LP1) are shifted in low energy region comparing with pure phonon modes in undoped SLs. The coupled modes are also broader. The effect of "softening" modes in the case of doping cannot be explained in frames of macroscopic approach [2]. The zeroes of dielectric constant with phonon and plasmon deposition gives the frequencies of LO-modes always

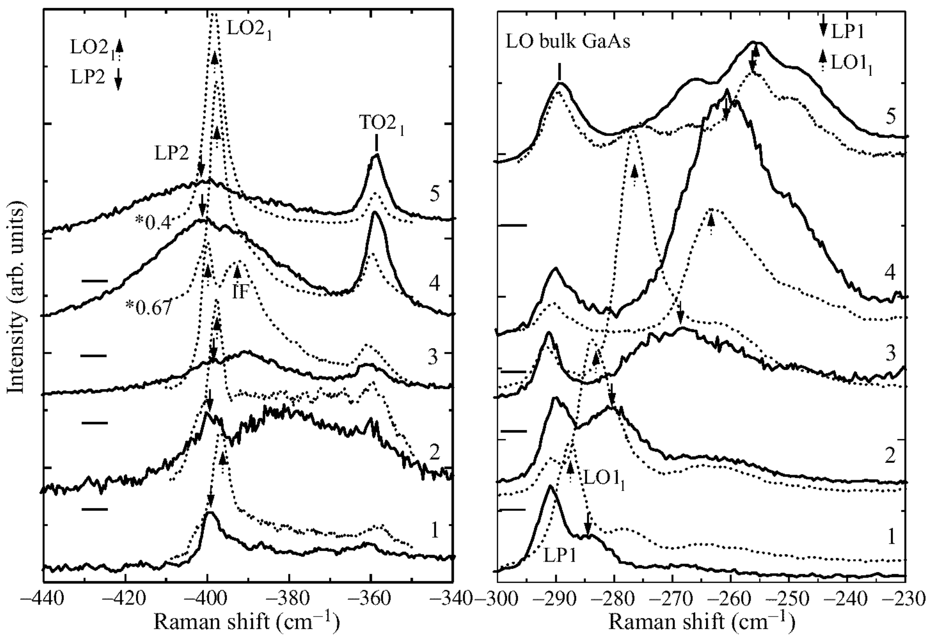


**Fig. 1.** Raman spectra in $(XY)$ geometry of doped (solid lines) and undoped (dashed lines) GaAs/AlAs SLs, grown on (001) substrate in the condition of $(2\times4)$ surface reconstruction. The directions $X$ and $Y$ are (100) and (010) correspondingly.

bellow the frequencies of pure LO modes. So, the more accurate approach is needed to calculate the dispersion of the coupled phonon–plasmon modes in tunnelling SLs. We have advanced microscopically approach for calculations of phonon–plasmon mode dispersion. The dynamic matrix of atomic vibrations was taken in "bond-charge" model. Phonons were considered as subsystem in dielectric media, which permittivity is defined by electron gas in Lindhard–Mermin approximation [3]. Long range dynamical screening of phonons by electron gas was taken into account by self-consistent solution for the dynamic matrix. The resultant dependence of frequencies of coupled phonon–plasmons on wave vector and frequency was derived, as well as corresponded Raman spectra. Some results are presented in Fig. 2(a).

The mass of electron along GaAs layer (mL) was the volume mass of electron, and the mass along direction of SL growth (mT) was changed. As on can see, at some volumes of mT, the frequency of phonon-GaAs-type phonon mode is low energy shifted, but the frequency of phonon-AlAs-type phonon mode is high energy shifted. The similar picture we can observe in the experiment. The wave numbers of LO1 modes of undoped and LP1 and LP2 modes of doped SL 3 are shown for comparison. The difference in Raman spectra of the phonon–plasmon modes was observed for the SLs containing the GaAs quantum well wires (QWWs) grown on corrugated (311)A surface and for (311)B SLs. The example is presented in Fig. 2(b). It is known, that surface (311)A are the very periodical massive of microfacets in direction Y $(\bar{2}33)$ [4]. The difference is supposed to be due to anisotropic dispersion of the phonon–plasmon modes along and across to GaAs quantum wires on faceted (311)A surface. For not-corrugated SLs grown on (311)B surface such anisotropy is absent, and its spectra are similar to spectra of (001) SLs. The anisotropy of TO phonons in (311)A corrugated SLs were observed earlier [5], the result of structural anisotropy

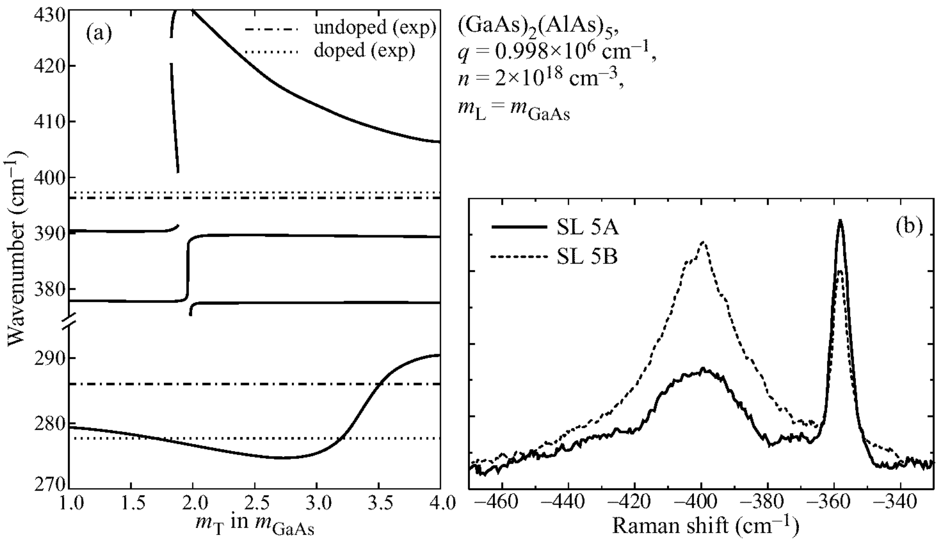


**Fig. 2.** (a) Calculated position of phonon–plasmons in $(GaAs)_3/(AlAs)_5$ SL. (b) The Raman spectra of doped SLs, grown on (311)A and B surfaces.

was splitting of TO phonon localized in QWWs, for modes with atom displacement along and across to QWWs. The structural anisotropy of (311)A SLs (undoped sample 5) was confirmed using HREM cross-section [6]. So, experimental and the theoretical results concerning phonon–plasmon interaction in tunnelling GaAs/AlAs SLs were obtained for the first time. The agreement between the experiment and the calculations is achieved. The difference in phonon–plasmon modes of (311)A and (311)B SLs was observed, it can be result of interface corrugation in (311)A SLs.

*Acknowledgements*

Russian Fund for Fundamental Research supported this work (grant No 99-02-16668). One of the authors (V. A. Volodin) is grateful to the Scientific Council of the Institute of Semiconductor Physics SB RAS for the Stipend for Young Scientists.

## References

[1] A. M. Mintairov, K. E. Smekalin, V. M. Ustinov and V. P. Hvosticov, *Semiconductors* **26**, 614 (1992).

[2] V. A. Volodin, M. D. Efremov and V. V. Preobrazhenski, *JETP Lett.* **71**, 698 (2000).

[3] M. Cardona, *Light Scattering in Solids IV. (Springer-Verlag, Berlin, 1982).*

[4] R. Nötzel, N. N. Ledentsov, L. Dawerits, M. Hohenstein and K. Ploog, *Phys. Rev. Lett.* **67**, 3812 (1991).

[5] V. A. Volodin, M. D. Efremov, V. V. Preobrazhenskii, B. R. Semyagin and V. V. Bolotov, *Superlatt. Microstructures* **26**, 11 (1999).

[6] N. N. Ledentsov, D. Litvinov, A. Rosenauer, D. Gerthsen, I. P. Soshnikov, V. A. Shchukin, V. M. Ustinov, A. Yu. Egorov, A. E. Zukov, V. A. Volodin, M. D. Efremov, V. V. Preobrazhenskii, B. P. Semyagin, D. Bimberg and Zh. I. Alferov, *J. Electron. Mater.* **30 (5)**, in print (2001).